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Original Research Article

Behind the fog: Forest degradation despite logging bans in an East African cloud forest

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A B S T R A C T

Habitat destruction and deterioration are amongst the main drivers of biodiversity loss. Increasing demand for agricultural products, timber and charcoal has caused the rapid destruction of natural forests, especially in the tropics. The Taita Hills in southern Kenya are part of the Eastern Afromontane Biodiversity Hotspot and represent a highly diverse cloud forest ecosystem. However, the cloud forest suffers extremely from wood and timber exploitation and transformation into exotic tree plantations and agricultural fields. Existing conservation regulations and moratoriums aim to prevent further forest destruction. In this study, we analyzed land cover change and shifts in landscape configuration for a fraction of the Taita Hills, based on satellite imageries for the years 2003, 2011 and 2018. We found that the coverage of natural cloud forest further decreased between 2003 and 2018, despite the effort to conserve the remaining cloud forest patches and to reforest degraded areas by various conservation and management initiatives. In parallel, the proportion of exotic tree plantations and bushland strongly increased. Moreover, mean natural forest patch size decreased and the degree of interspersion with other land cover types increased notably. Logging bans for indigenous trees seem to have resulted in local opposition to the planting of indigenous trees and thereby hindered the recovering of the cloud forest. We suggest to enhance local awareness on the ecological value of the natural forest by community-based Conservation Forest Associations and to encourage the planting of indigenous tree species in farmer-owned woodlots. Besides, bottom-up management systems that allow for local participation in decision-making and benefit-sharing related to forest resources would be a way forward to achieve the sustainable use and conservation of the last remaining natural forest patches in the Taita Hills.

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1. Introduction

A growing human population and increasing living standards cause the need for more land and natural resources, which has led to the transformation of natural and semi-natural ecosystems into intensively used agricultural land, tree plantations, and settlements worldwide (Achard et al., 2002; Tscharntke et al., 2005). This trend causes the fragmentation of former interconnected habitats, and the deterioration of habitat quality in the remaining habitat patches (Watson et al., 2005; Richard and Armstrong, 2010). Finally, these impacts negatively influence the persistence of many more specialized animal and plant species (Lindenmayer, 2019; Volenec and Dobson, 2019) and disrupt community structures and ecosystem stability (Wilson and Rhemtulla, 2018). Tropical forests suffer in particular from human population pressure, lack of effective land management, and non-sustainable use of natural resources (Haddad et al., 2015). While large-scale deforestation takes place in southern America (Barrett et al., 2013) and in southern Asia (Sodih et al., 2004; Gibson et al., 2011; Koh et al., 2011), African forests are threatened by small-scale logging and wood extraction, however with comparable disastrous long-term effects (Hosonuma et al., 2012).

Kenya contains a large variety of different forest types, such as lowland rain forest, dry coastal forest, and montane cloud forests (Peltorinne, 2004). Nowadays, most of these forests are fragmented and degraded to various degrees (Pellikka et al., 2004). To stop further deforestation and forest degradation, various national laws and regulations as well as regional logging bans for public forests were repeatedly passed during the past 30 years (KMEF, 2018b), such as a logging ban on indigenous timber released under president Moi in 1998, Kenya Forests Act in 2005, forest (charcoal) regulations in 2009, Forest Conservation and Management Act (Kenya Gazette Supplement, 2016), and various regional bans (during the mid-1990s) (Wass, 1995; The World Bank, 2007; KMEF, 2018b). More recently, the Kenyan Ministry of Environment and Forestry (KMEF) enacted a nation-wide logging ban for all public and community forests in response to increasing water scarcity due to the latest drought events (KMEF, 2018a).

In view of these regulations, and especially the latest 2018 national logging ban, the present study evaluates recent trends of land-cover changes and forest degradation for a fraction of the Taita Hills in southern Kenya. This mountain range was formerly covered by cloud forest and is home to a large number of endangered endemic plant and animal species (Beentje, 1988; Brooks et al., 1998a) as well as to more than 300,000 people (KNBS, 2009). Furthermore, this area belongs to one of the 36 global biodiversity hotspots (Mittermeier et al., 2011). Continued forest transformation and the exploitation forest resources have diminished forest cover and forest quality considerably (Githiru and Lens, 2007; Aerts et al., 2011). This negative trend impacts in particular typical forest plant (Pellikka et al., 2009, 2013) and animal species (Lens et al., 2002). The 12 last remaining forest patches in the Taita Hills make up only 2% of the original cloud forest cover (Newmark, 1998) and are mainly located on steep, inaccessible slopes, or protected due to cultural beliefs (Pellikka et al., 2009).

This study updates work of Pellikka et al. (2009) and focuses on land cover change and habitat configuration in the Taita Hills between 2003 and 2018 based on three timestamps (2003, 2011, 2018). We first analyse land cover changes (i.e. change from forest to non-forest, change from natural broadleaved forest to exotic tree plantation) based on high-resolution satellite imagery. Then, we critically evaluate the efficiency of forest conservation and land management policies implemented at the local, regional and nation level in view of our results.

2. Material and methods

2.1. Study area

The Taita Hills in southern Kenya form the northernmost edge of the Eastern Arc Mountains (Newmark, 2002; Burgess et al., 2007) and are part of the Eastern Afromontane Biodiversity Hotspot (Mittermeier et al., 1998). Annual rainfall is divided into long rains from March until May, and short rains with variable onset from October until December, with total annual rainfall between 1100 mm and 1400 mm (Jaetzold et al., 2012). The hilltops reach a maximum elevation of 2208m a.s.l. (Maeda et al., 2010), and were originally covered by cloud forest (Pellikka et al., 2009). This forest has a unique biodiversity, with many endemic and highly endangered species, such as the Taita Thrush (*Turdus helleri*) or Taita Apalis (*Apalis fuscigularis*) (Brooks et al., 1998a; Mulwa et al., 2007; BirdLife International, 2019). The 12 remaining forest patches are mostly small (on average 38ha, ranging from <1 to 220ha). Only three larger forest blocks remain, with two of them being still relatively undisturbed. The smaller forest patches show very low habitat quality (Aerts et al., 2011). The forest provides various ecosystem services and resources, such as timber for construction, firewood, charcoal and livestock grazing ground (Pellikka et al., 2009, 2013). Furthermore, the Taita Hills are classified as important Water Tower System (KWTA, 2018).

Most of the people in the Taita Hills depend on subsistence agriculture and cultivate food crops or fodder crops such as maize, beans, tomatoes, cassava, peas, cabbage, potatoes, mango and banana (Jaetzold et al., 2012). The human population increased from 111,000 people to more than 300,000 people between the years 1969 and 2009 (KNBS, 2009). This severe demographic pressure negatively affected soil fertility, soil stability and the hydrology of the Taita Hills (Muya and Gicheru, 2005; Pelllikka et al., 2013). Forest habitat quality is reduced due to human encroachment and resource exploitation (Rogo and Oguge, 2000; Aerts et al., 2011). The protection status of most of the remaining forest fragments is unclear since only few of the fragments (Ngangao, Fururu, Ndiwenyi, Susu, Macha, Mwachora) are gazetted as forest reserves and managed by the Kenyan Forest Service (Kenya Gazette Supplement, 2016) (c.f. Wass, 1995; Matiru, 1999; Lanne, 2007). Other forest fragments (Chawia, Mbololo, Msidunyi and Vuria) are community forests and thus remain without official conservation status

(Kenya Gazette Supplement, 2016). Overall, the Taita Hill cloud forest is considered as one of the most threatened forests worldwide (Lovett and Wasser, 1993; Burgess et al., 2007; Githiru et al., 2011). In this study we focus on a 109 km^2 fraction of the southern Taita Hills, which includes privately owned agricultural land, exotic tree plantations, one large (86 ha) unprotected community forest (Chawia), and another smaller (12 ha) highly degraded forest patch (Fururu) (Fig. 1).

2.2. Satellite remote sensing and land cover classification

Land cover change assessment was conducted with multispectral satellite imagery of the SPOT series (Centre National d'Etudes Spatiales, 2015). We used SPOT 4 data, with 20m geometric resolution and 4 spectral bands consisting of green (500–590 nm), red (610–680 nm), near-infrared (NIR) (790–890 nm) and infrared (1580–1750 nm) for the years 2003 and 2011. For the year 2018 we used SPOT 7 imageries, with a 6 m geometric resolution and blue (455–525 nm), green (530–590 nm), red (625–695 nm), and NIR (760–890 nm) spectral resolution (Table 1). All satellite images were taken with similar sensor settings during October of the respective years, and thus represent the condition of the end of dry season or the onset of the shorter more variable second rainy season (Jaetzold et al., 2012). The images were radiometrically corrected using the Geosud ToA Reflectance Plugin (Ose, 2015), which performs a conversion from Digital Pixel Numbers to milli-reflectance values; topographic correction of reflectance was done using GRASS module extension within QGIS. We considered the following land cover categories (according to the FAO Land Cover Classification System, Di Gregorio, 2016): (i) Indigenous forest (in the following named natural forest), (ii) mixed forest (i.e. natural forest mixed with exotic trees), (iii) exotic tree plantation, (iv) bushland/shrubland/woodland (hereafter referred as bushland), (v) cropland, (vi) built-up area & bare soil/rock and other unconsolidated material, and (vii) grassland (for details see Appendix S1). Categories were ground-truthed during fieldwork in August 2018. Visual interpretation of land cover types was performed based on imagery and expert knowledge. For the initial classification, we used the semi-automatic classification plugin for QGIS (Congedo, 2016) and performed a supervised land cover classification for all three years, applying the minimum distance algorithm (Tso and Mather, 2009; Li et al., 2014; Abburu and Golla, 2015). Changes in land cover types and area were analyzed by means of the QGIS plugin Molusce (NextGIS and Asia Air Survey, 2013). In order to detect areal changes, datasets were resampled to 20m geometric resolution and aligned properly to ensure spatial co-registration (Foody, 2001). The classes 'cloud' and 'cloud shadow' were assigned to the class 'unclassified' (in total 0.06 km^2 (0.06%), 5.92 km^2 (5.43%) and 1.89 km^2 (1.73%) for the years 2003, 2011 and 2018, respectively). Changes in land cover were analyzed by area change, percentage change, and change trajectory.

2.3. Statistics

Classification accuracy assessment was conducted based on Error matrix and Kappa statistics (Monserud and Leemans, 1992; Pontius, 2000). Using ground truthing data, expert knowledge and Google Earth inspection, overall accuracies of 83.5% (2003), 85.3% (2011) and 80.7% (2018) were achieved (for a complete Error Matrix see Appendix S2). To assess changes in landscape configuration and composition, we computed the following metrics based on 100 randomly sampled tiles (500m edge length) using the program Fragstats 4.2 (McGarigal, 2015): 1. Clumpiness Index (CLUMPY), landscape texture (aggregation) in terms of the spatial intermixing of different land cover categories; 2. Patch Cohesion Index (COHESION), measurement of physical connectedness of land cover categories; 3. Effective Mesh Size (MESH), land cover category size with regard to total area (for details see Appendix S3). Significant differences between the years were tested with Kruskal-Wallis tests (Kruskal & Wallis, 1952) using the software R (R Core Team, 2019).

3. Results

In the time period from 2003 to 2011, we found highest land cover change in the study area for mixed forest (+63.0%) and bushland (−44.0%). There was also a strong increase in exotic tree plantations (+71.4%) and a decrease in built-up area & bare soil/rock (−21.3%). During the same time period, natural forest cover slightly increased (+20.0%), as well as the cover of cropland (+5.9%) and grassland (+4.3%). In the time period from 2011 to 2018, we found severe changes for the coverage of exotic tree plantations (+166.7%), cropland (−58.1%), bushland (+156.0%) and natural forest (−27.8%). Built-up areas and bare soil/rock increased by 70.0%, and marginal changes were unveiled for grassland (+0.5%) for the same time period. Across the entire study period (2003–2018), we found the strongest changes in land cover for exotic tree plantations, which increased by 357.1%, while cropland decreased by 55.6%. Natural forest cover decreased by 13.3% and bushland cover increased by 43.3%. Mixed forest cover increased by 35.6% and cover of built-up area and bare soil/rock by 33.7%. Marginal gains occurred for grassland (+4.8%). An overview of land cover changes (2003–2011, 2011–2018, 2003–2018) is given in Table 2.

Besides area changes over time, a change trajectory analysis quantified the proportional gains and losses between land cover classes. From 2003 to 2011, most changes occurred from all classes into cropland (e.g. 42% of the former grassland changed into cropland). Substantial transition also occurred from natural forest into mixed forest (23%). Least changes were observed from bushland, cropland, built-up area and bare soil/rock, and grassland into natural forest and plantation of exotic trees, and from built-up areas and bare soil/rock to mixed forest class (4%). For the time period from 2011 to 2018, we found major changes from all classes (except built-up area and bare soil/rock) into bushland. Furthermore, substantial change occurred from built-up area and bare soil/rock (36%) and cropland (24%) to grassland, and from natural forest (29%) and exotic

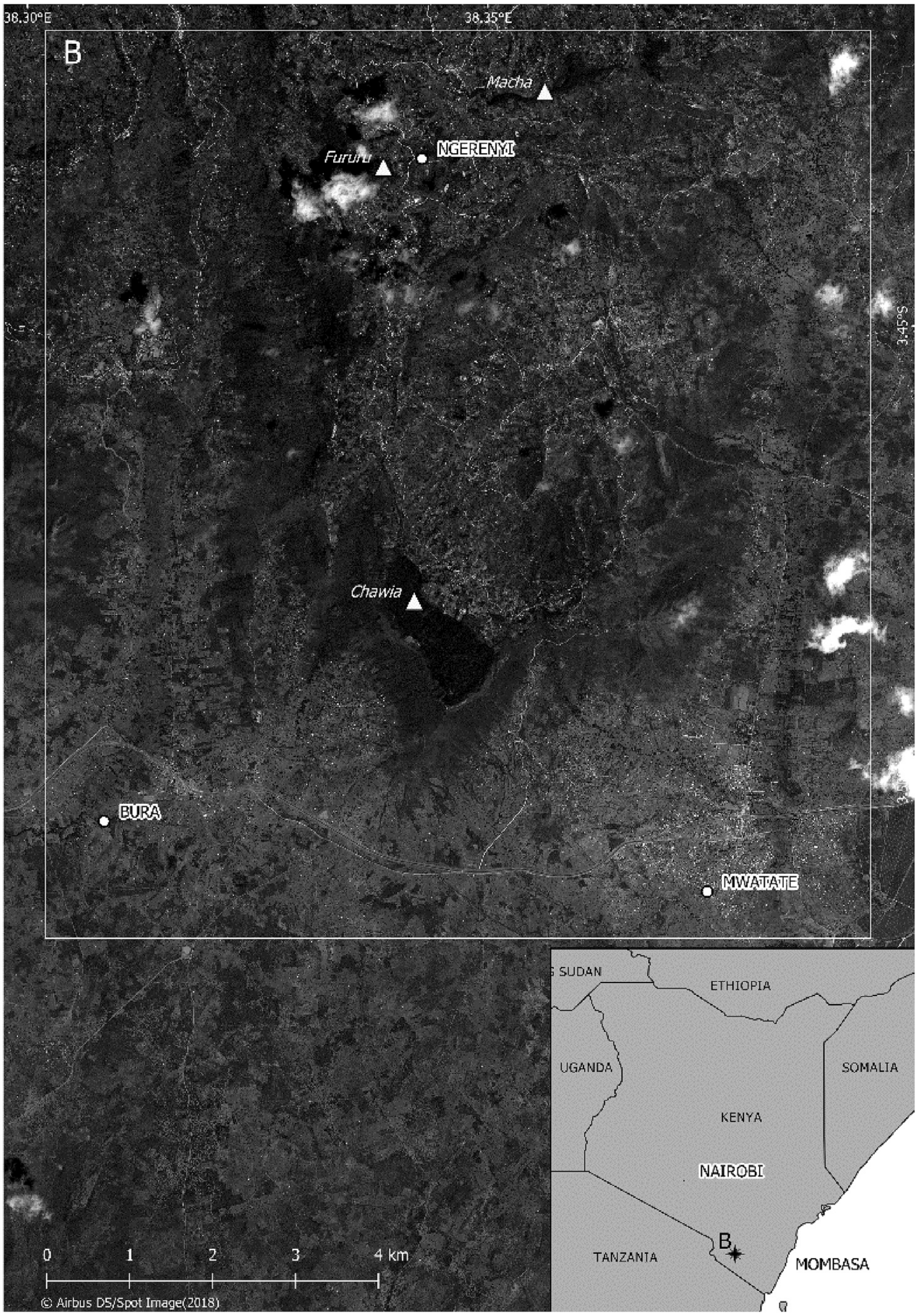

Fig. 1. Location of our study area in Kenya (small inlet map A) and the section (white rectangular) for which land-cover changes have been analyzed, and names of the forest fragments (triangles) and major settlements (circles) in the study region.

Table 1
Characteristics of the SPOT remote sensing data used for classification in 2003, 2011 and 2018.

Date/Time UTC	Sensor	Sensor view angle	Solar azimuth angle	Solar elevation angle
15.10.2003 07:49	SPOT 4 HRVIR 1	10.4°	104.3°	69.0°
23.10.2011 07:05	SPOT 4 HRVIR 1	26.2°	105.7°	58.1°
01.10.2018 07:25	SPOT 7	13.196°	89.59°	62.35°
15.10.2018.07:18	SPOT 7	26.07°	100.82°	60.91°

plantation forest (33%) into mixed forest (Table 3). Change trajectories (2003–2011, 2011–2018, 2003–2018) are shown in Fig. 2.

Kruskal-Wallis-tests revealed significant differences in habitat configurations among years for the following indices: CLUMPINESS and COHESION for all classes, except natural forests and built-up area and bare soil/rock. MESH showed significant differences in habitat configurations for the land cover classes mixed forest, grassland, cropland, and bushland. Dunn-Bonferroni corrected post-hoc tests revealed the following trends for the overall time period from 2003 to 2018: The CLUMPINESS index significantly decreased for all land cover classes, except for natural forest (slight decrease), which is an indicator for increasing disaggregation and thus interspersion. The COHESION index, i.e., connectedness of patches of the same land cover type, decreased for cropland, mixed forest, plantation of exotic trees, grassland and built-up areas and bare soil/rock. The MESH index decreased significantly for mixed forest and cropland and slightly increased for bushland. All details are shown in Fig. 3 and Table 4.

4. Discussion

Land cover in the Taita Hills changed considerably during the studied time period. Between 2011 and 2018, we found a significant increase in bushland and in parallel a decrease in cropland. In fact, major areas of cropland changed into bushland during that time period. Natural forest was mainly converted into mixed forest (dominated by exotic tree species) and cropland from 2003 to 2011, and more recently (from 2011 to 2018), into pure plantations of exotic trees and bushland. Although the accuracy assessment of conducted classification revealed only moderate results (Appendix S2) we will discuss the drivers of the observed land cover changes and challenges to the efficient conservation of the last remaining natural cloud forest patches in the Taita Hills.

4.1. Habitat destruction and land abandonment

The conversion of natural forest in cropland, and subsequently into bushland (i.e. fallow land) has been frequently observed in tropical forest areas (Reynolds et al., 2015). Potential drivers may arise from global climate trends, local topographic and abiotic soil conditions, as well as socio-economic factors, such as demographic pressure and increasing urbanization:

1. Demographic pressure is particularly high for the Taita Hills if compared with other regions across Kenya (KNBS, 2013, 2009). This has caused a high demand for cropland for several decades as documented by previous studies (Pellikka et al., 2013). This trend is reflected in our results for the time period 2003 to 2011. However, our data indicate a turnaround for the more recent years, with an increase in bushland as a succession of former cropland, which may reflect the current rural exodus. Kenya shows rapid urbanization rates (e.g., 4.3% for the year 2016) (Fengler, 2010; The World Bank, 2019) and especially for Taita Taveta County with a rise from 14.3% in 1999 to 25% in 2009 (KNBS, 2009).
2. Ongoing transformation of natural forest into new cropland and/or fallow land is often a consequence of non-adapted farming techniques, such as a lack of crop rotation, little crop diversification and lack of soil fertility management (Soini, 2005; Githiru et al., 2011; Jaetzold et al., 2012). The Taita Hills are characterized by intense cultivation even on steep slopes, which causes soil erosion, reduces soil fertility (Jaetzold et al., 2012; Pellikka et al., 2013; Hohenthal et al., 2015), and subsequently leads to an increasing proportion of unproductive area, i.e. fallow land.
3. Increased abandonment of croplands in the Taita Hills may also stem from climate change effects, such as changing rainfall patterns and unreliable seasonal rains (Hohenthal et al., 2015; Githiru and Lens, 2007; Taita Taveta County Government, 2019). In addition, the destruction of natural forest reduces the rate at which rainwater seeps into the ground and increases surface runoff. In the Taita Hills, the drying up of local wells and reduced water discharge at outlets has already caused severe water scarcity, resulting in economic drawback for local farmers and decreasing agricultural productivity (Hohenthal et al., 2015).
4. ‘Off-farm’ income, i.e. non-agricultural labour may also contribute to farmers leaving exhausted and dry agricultural plots, which subsequently turned into bushland during the past years (Soini, 2005; Githiru et al., 2011).

Table 2
Area (in km^2) and proportional changes (%) of the respective land cover classes over the time period from 2003 until 2018.

Land cover class	2003		2011		2018		Δ 2003–2011	Δ 2011–2018	Δ 2003–2018
	km^2	%	km^2	%	km^2	%	km^2	km^2	km^2
Mixed forests	7.3	6.7	11.9	10.9	9.9	9.1	4.6	−2.0	2.6
Natural forests	1.5	1.4	1.8	1.6	1.3	1.2	0.3	−0.4	−0.2
Exotic tree plantation	0.7	0.7	1.2	1.1	3.2	2.9	0.4	2	2.4
Grassland	21.0	19.3	21.9	20.1	22.0	20.2	0.9	0.1	1.0
Cropland	41.0	37.7	43.4	39.8	18.2	16.7	2.4	−25.3	−22.9
Bushland/Shrubland/Woodland	28.4	26.0	15.9	14.7	40.7	37.3	−12.5	24.8	12.3
Built-up and bare soil/rock	8.9	8.1	7	6.4	11.9	10.9	−1.9	4.9	3.0
Unclassified	0.1	0.1	5.9	5.4	1.9	1.7	5.9	−4.0	1.8

Table 3
Transition matrix for land cover classes showing proportional shift between classes for the time 2003 and 2011, and 2011 and 2018 divided by a slant.

Land cover class	Natural forest	Exotic tree plantation	Mixed forest	Bushland/shrubland/ woodland	Cropland	Built-up & bare soil/ rock	Grassland
Mixed forest	0.06/0.02	0.05/0.06	0.20/0.16	0.12/0.42	0.35/ 0.14	0.04/0.05	0.16/0.12
Natural forest	0.15/0.11	0.09/0.14	0.23/0.29	0.11/0.27	0.22/ 0.10	0.06/0.02	0.11/0.04
Exotic tree plantation	0.08/0.10	0.13/0.17	0.15/0.33	0.11/0.23	0.33/ 0.09	0.05/0.02	0.12/0.02
Grassland	0.00/0.01	0.00/0.02	0.08/0.07	0.12/0.37	0.42/ 0.17	0.09/0.11	0.23/0.22
Cropland	0.01/0.01	0.01/0.02	0.10/0.08	0.14/0.33	0.43/ 0.19	0.05/0.12	0.21/0.24
Bushland/Shrubland/ Woodland	0.02/0.01	0.01/0.02	0.14/0.08	0.20/0.52	0.34/ 0.16	0.03/0.08	0.19/0.12
Built-up and bare soil/rock	0.00/0.01	0.00/0.02	0.04/0.07	0.08/0.37	0.48/ 0.17	0.19/0.11	0.17/0.22

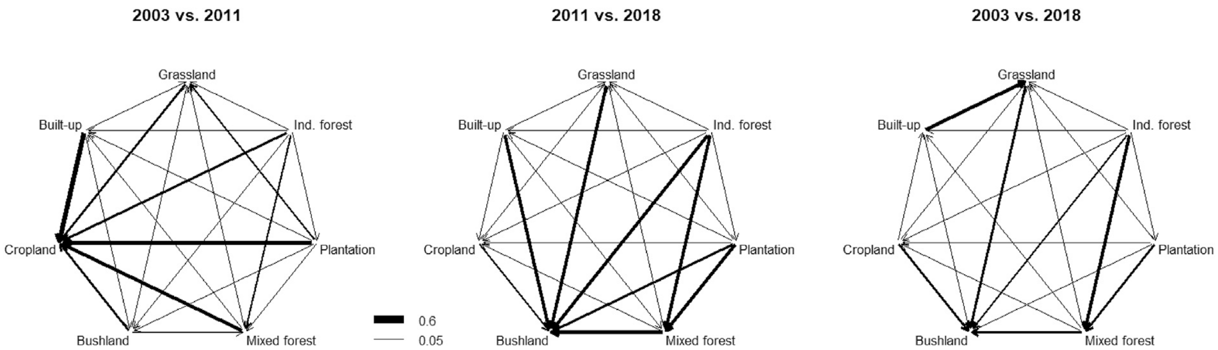

Fig. 2. Transition matrix diagram for land cover classes showing proportional shift between classes for the time 2003 vs. 2011, 2011 vs. 2018 and 2003 vs. 2018, expressed as width of arrows. Proportional shifts <0.05 were suppressed.

4.2. Forest cover and forest type

Our land cover change analysis documents an increase in forest cover (2003: 9.5 km^2; 2011: 14.9 km^2; 2018: 13.6 km^2) for the study area. This trend was mainly due to an increase in the coverage of exotic tree plantations, while natural forest cover is still decreasing. Previous studies in the Taita Hills documented constant forest cover, but changes in tree species composition from broadleaved forest into exotic tree plantations for the time period from 1955 to 2004 (Pellikka et al., 2009). In consequence, natural forest decreased by more than 50% during this time period (Pellikka et al., 2009). Our results underpin that the remaining natural cloud forest (only 2% of the original forest cover, Newmark, 1998) is under extreme pressure.

The large-scale planting of exotic trees (i.e. cypress, eucalyptus, pine, silver oak) reaches back to the colonial era in the 1960s (Brooks et al., 1998b), and was continued afterwards within the framework of the Kenya Forest Department policy until the 1980ies (Githiru et al., 2011). This policy aimed to support farmers with timber and wood production and to reduce pressure on the natural forest remnants (Pellikka et al., 2013; Hohenthal et al., 2015). However, plantations of exotic trees mostly do not provide suitable habitats for typical cloud forest species and thus negatively affect biodiversity (Lens et al., 1999). Furthermore, changes in tree species composition may impact ecosystem services such as ground water levels or stream flows (Scott and Lesch, 1997; Scott et al., 2005), which is particularly the case for eucalyptus plantations (Del Moral and Muller, 1970; Jagger and Pender, 2003). Plantations of exotic trees are also less effective carbon sinks due to their lower biomass and sparse undergrowth if compared with natural cloud forest (Pellikka et al., 2009; Liao et al., 2010; Omoro et al., 2013).

4.3. Increasing habitat fragmentation

Our data indicate a continuing reduction in patch size, patch aggregation, connectedness and increased patch interspersion for the remaining cloud forest in the study area, and it can be assumed that this is representative of the overall forest cover trends in the Taita Hills. This trend may further diminish habitat quality of the remaining cloud forest patches, due to negative edge effects as documented elsewhere in cloud forests (Laurance et al., 2002). Previous studies showed that most forest remnants in Taita Hills only hold a fraction of the original fauna (e.g. birds, Brooks et al., 1998b; Lens et al., 2002), and typical forest bird species (e.g. Taita Apalis, *Apalis fuscigularis* and Taita Thrush, *Turdus helleri*) show only limited gene flow

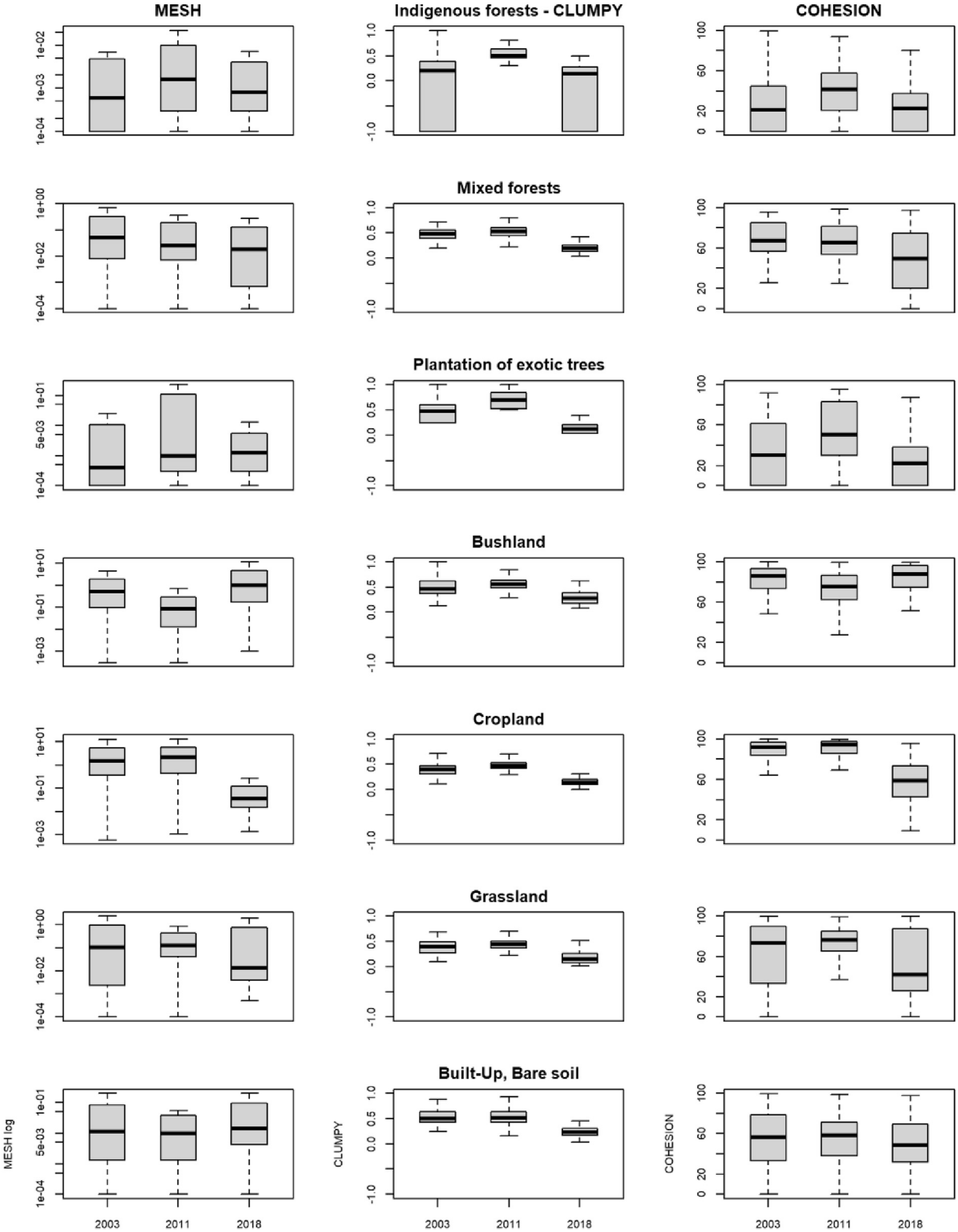

Fig. 3. Results for the calculated landscape metrics (Effective Mesh Size, Clumpiness, Patch Cohesion) according to the land cover classes and the three timestamps.

Table 4
Results of Kruskal-Wallis tests regarding the indices CLUMPY, COHESION and MESH, and significant differences according to Dunn-Bonfferoni post-hoc tests. Level of significance is indicated by *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$.

Land cover class	Kruskal-Wallis H-test			CLUMPY			COHESION			MESH		
	CLUMPY	COHESION	MESH	2003–2011	2011–2018	2003–2018	2003–2011	2011–2018	2003–2018	2003–2011	2011–2018	2003–2018
Mixed forests	*** H(2) = 123.230	*** H(2) = 8.729	*** H(2) = 6.497		***z = 10.720	***z = 7.564		***z = 3.777	***z = 3.804			*z = 2.337
Natural forests	*** H(2) = 45.575			***z = −5.069	***z = 6.297							
Exotic plant-ation forests	*** H(2) = 47.872	*** H(2) = 13.223		*z = −2.580	***z = 6.585	***z = 3.708		***z = 3.439				
Grassland	*** H(2) = 120.479	*** H(2) = 18.427	*** H(2) = 9.177	**z = −2.654	***z = 10.643	***z = 7.424		***z = 3.812			**z = 3.021	
Cropland	*** H(2) = 192.248	*** H(2) = 123.453	*** H(2) = 109.947	***z = −4.240	***z = 13.561	***z = 9.297		***z = 10.172	***z = 8.867		***z = 9.460	***z = 8.656
Bushland/Shrubland/ Woodland	*** H(2) = 105.976	*** H(2) = 26.541	*** H(2) = 47.815	*z = −2.698	***z = 9.949	***z = 7.244	***z = 3.663	***z = −5.018		***z = 4.550	***z = −6.786	
Built-up and bare soil/ rock	*** H(2) = 131.947				***z = 10.064	***z = 9.609						

among forest patches (Lens et al., 1999; Callens et al., 2011). Thus, it is crucial to increase cloud forest connectivity to safeguard populations and species (Lens et al., 2002; Aben et al., 2012; Haddad et al., 2015). Increasing proportions of bushland (due to the abandonment of cropland) may support landscape permeability (Hadley and Betts, 2009; Gillies & St. Clair, 2010; Aben et al., 2012). However, the increasing dominance of exotic trees in the Taita Hills (Piiroinen et al., 2017) negatively impact typical forest species, such as birds (Lens et al., 1999) and herbivorous arthropods (Habel et al., 2018a), as they only rarely represent a surrogate habitat for forest species (Kehlenbeck et al., 2011; Habel et al., 2018b; Goded et al., 2019).

4.4. Logging bans and regulations

Despite the national efforts to stop deforestation, natural forest cover has been decreasing over the last 60 years in Taita Hills. We identify two phases of cloud forest destruction: The first phase was characterized by large-scale commercial tree planting (predominantly eucalyptus), mainly governmental initiatives for forest management (Brooks et al., 1998b; Githiru et al., 2011). In the second phase, local people transformed natural forest into fields for subsistence agriculture and continued planting exotic trees in small woodlots across the Taita Hills (Pellikka et al., 2013). The existing logging bans and regulations did not prevent the destruction and degradation of natural forest in the Taita Hills (Pellikka et al., 2009). Most of the management strategies were implemented by national governmental policies (Keeley and Scoones, 2003; Seghezzo et al., 2011; Cáceres et al., 2016). For instance, first efforts to conserve the remaining cloud forest were made in 1977, by the presidential decree of banning the logging of indigenous tree species (Himberg et al., 2009; Pellikka et al., 2013). In the early 1980ies bans on cutting natural forest continued by presidential directive, however the conversion of natural forest into exotic tree plantations was still allowed until 1984 (Beentje, 1988; Mbuthia, 2003; Himberg et al., 2009).

Most of the governmental management strategies were influenced by economic concerns and discouraged sustainable behaviour of local people due to lack of participatory approaches (The World Bank, 2007). Religious, cultural, and intrinsic ecological behaviour traditionally linked to the forest by the local community was not considered here (Wass, 1995). Although a new forest act introduced the concept of Participatory Forest Management (PFM) in 2005, the pronounced time period of top-down forest management discouraged sustainable community behaviour as was also observed in other parts of Africa (Robertson and Lawes, 2005; Odera, 2009; Tadesse and Teketay, 2017).

Overall, inefficient institutional frameworks and lack of communication between the government and local farmers caused misunderstanding in terms of rights and obligations in forest management and the use of forest resources (Sifuna, 2009; KWTA, 2018). Today, the remaining cloud forest patches of the Taita Hills are managed by different organizations: Ngangao, Fururu, Ndiwenyi, Susu, Macha, Mwachora are gazetted and protected forest and managed by the Kenyan Forest Service; Chawia, Mbololo, Msidunyi and Vuria are non-gazetted forests, Ngangao has only recently been gazetted, and large parts of Vuria and Msidunyi are privately owned land (Susu Ndiweni Fururu Community Forest Association, 2018). There is an urgent need to clarify responsibilities and to develop a sustainable forest management plan.

There are some further reasons why conservation efforts in the Taita Hills (Githiru and Lens, 2007; Githiru et al., 2011), such as the creation of awareness on the uniqueness of Taita Hill biodiversity and the planting of (indigenous) trees (Susu Ndiweni Fururu Community Forest Association, 2018), were of only little success - until today:

1. Farmers were encouraged to cultivate indigenous tree seedlings (c.f. Forest Conservation and Management Act, 2016), yet the common exotic species in the study area (E. *camaldulenis*, *Grevillea robusta*, *A. mearnsii*) continue to be of high socio-economic importance, e.g., as timber or fuelwood (charcoal) (Orwa et al., 2009; Hohenthal et al., 2015; Thijs et al., 2015). There are only few indigenous tree species that are favored by local farmers, such as *M. lanceolata* (commonly used as life fence, fuelwood and medicine) (Tesemma et al., 1993). Furthermore, the Kenyan Forest Service still supports commercial forestry and the plantation of exotic trees (Hohenthal et al., 2015, Hohenthal_et_al_2018), and there is a lack of indigenous sapling in local tree nurseries (own observations).
2. Weak partnerships and communication between stakeholders initiating and implementing forest-related programs led to the duplication, overlapping or even contradictory conservation initiatives (Hohenthal et al., 2015; KWTA, 2018).
3. Contributing to a minimal extent, traditions like attracting rainfall by forest fires may damage forest rehabilitation areas (Hohenthal et al., 2015).
4. Due to rapid propagation of seeds and saplings of exotic species (i.e. E. *camaldulenis)* with high annual height and diameter increments (up to 3m in size per year), characteristic forest species are not competitive enough. Thus, especially in sensitive areas in the periphery a gradual alteration of forest tree species composition will take place, by further promoting the planting of exotic species, including invasive species such as *Acacia mearnsii* (Orwa et al., 2009).

4.5. Sustaining last Taita Hill cloud forest patches

Our study showed that poor enforcement of policies, multiple contradictory regulations, and at the same time a lack of clear governmental regulations and awareness among forest adjacent communities have negatively impacted the remaining natural forest patches. We would like to close our contribution by formulating two steps towards efficient cloud forest preservation in Taita Hills:

1. Forest management needs to rely more strongly on bottom-up systems, whereby local people are part of decision-making and monitoring processes and have responsibility for managing their forest livelihoods. First steps towards community-based management were provided by the newly ratified Forest Act in 2007, with emphasis on government-private sector partnerships. The 2007 Forest Act rendered the management of forest more transparent and established stronger focus on accountability and revenue generation by the transformation of the former Forest Department into the independent Kenya Forest Service (KFS). Out of the existing 325 Community Forest Associations across Kenya, only 99 have officially signed management agreements with KFS, and thus are operating in accordance with the law (KMEF, 2018b). Positive effects of bottom-up systems, such as PFM are known from other regions in Kenya (Ogada, 2012; Thygesen et al., 2016; Benjamin and Blum, 2015) and other parts of East Africa (Jagger, 2008; Ameha and Lemenih, 2014; Samii et al., 2014). However, the success of such approaches often relies on localized human-nature relationships and may depend on the ethnicity of people, as shown for the Arabuko Sokoke coastal forest in Kenya (Nzau et al., 2020). Other bottom-up activities include environmental education and research, like the local Dabida Biodiversity Conservation group which offers guided tours and workshops on sustainable use.
2. Previous studies showed that deforestation, forest degradation and exotic species plantations (e.g. eucalyptus) may lead to a decrease in biodiversity and various ecosystem services, (Thijs et al., 2014; Liang et al., 2016; Lohbeck et al. 2018; Schmitt et al., 2019), such as water availability (Hohenthal et al., 2015). Therefore, we advise to increase tree cover across agricultural areas using indigenous tree species and to promote these tree species in local nurseries. Ideally, farmers could combine woodlots of exotic species planted for timber and wood production, with tree plantations and agroforestry systems based on indigenous trees, which may also provide non-timber forest products. In addition, there is an urgent need of reforesting open and degraded areas with indigenous tree species to substantially improve habitat networks for diverse species and forest-related ecosystem services. The planning of such measures and the effectiveness heavily depend on overall functional connectivity and should be guided by the use of Spatially Explicit Population Models (SEPMs) to evaluate potential changes of landscape in advance (Aben et al., 2016, 2018; Synes et al., 2016). Furthermore, the use of such SEPMs would also improve organization and thus effectiveness of PFM initiatives.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01024.

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